

VISIT...

LANZAROTE
Caliente.COM



NEUROPROSTHETICS FOR RESTORATION OF UPPER LIMB FUNCTION

Jennifer Collinger
October 18, 2014

Email: collingr@pitt.edu

Motivation

2

- People with severe disabilities may have limited means to communicate or interact with their environment
- Traditional assistive technologies often require some amount of dexterity to operate
- A brain-computer interface (BCI) can establish a direct link between the brain and an external device
 - ▣ Potential for high degree-of-freedom, intuitive control
 - ▣ Rehabilitation

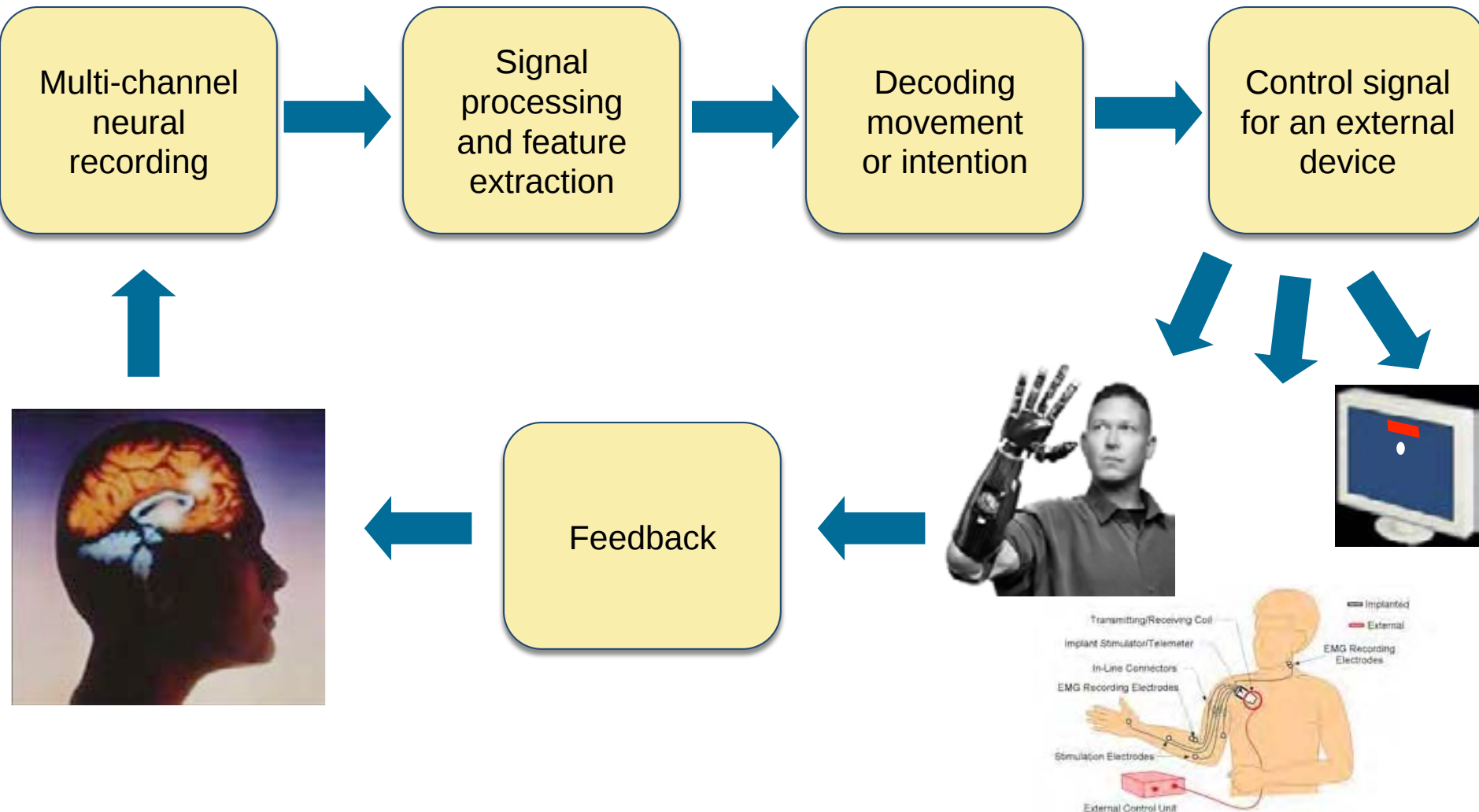
Outline

3

- Definition of BCI/ neuroprosthesis
- Multidisciplinary research approach
- BCI for neurorehabilitation
- BCI as assistive technology
 - User Priorities
 - Clinical research at Pittsburgh
- Barriers to clinical translation

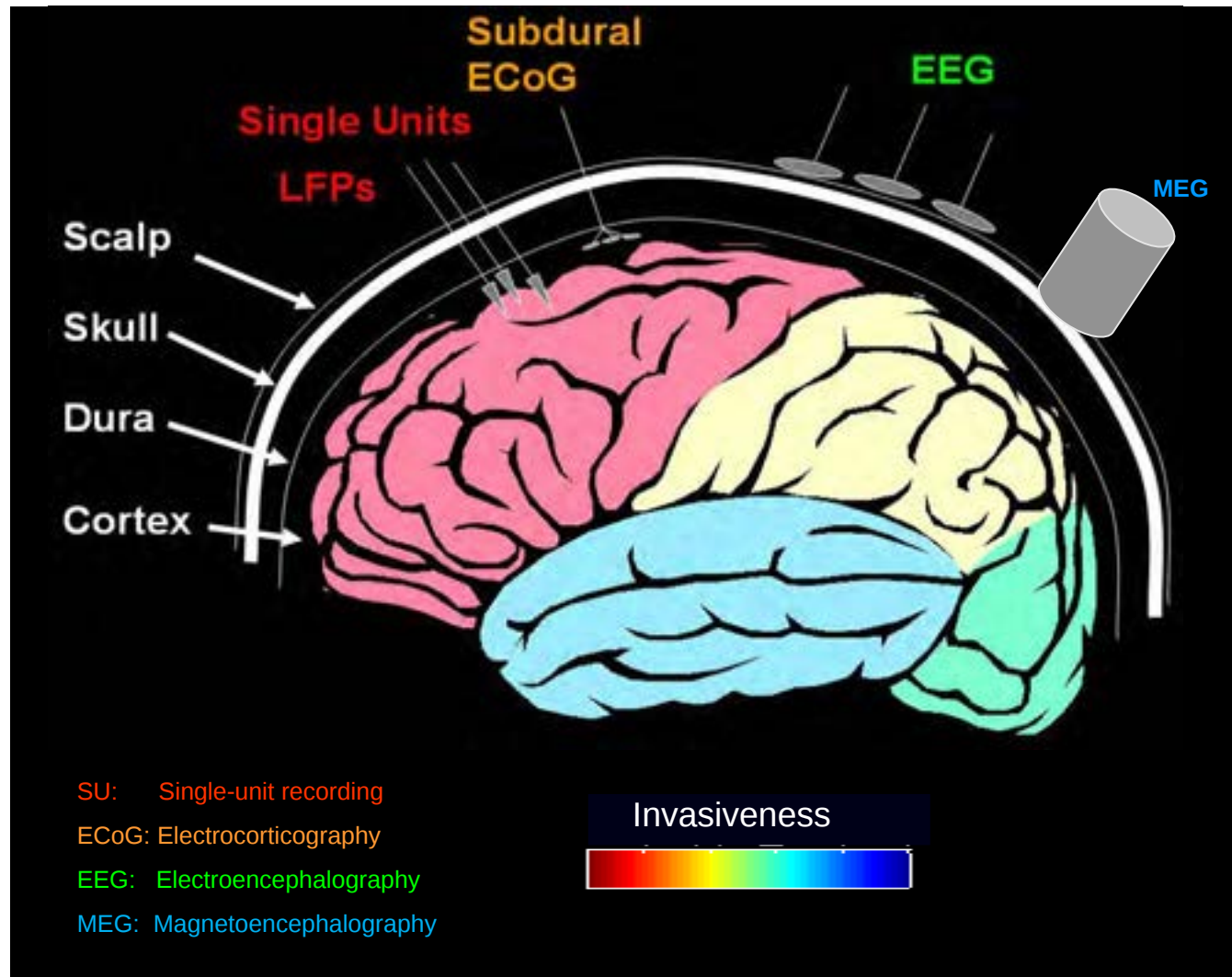
Brain-computer interfaces (BCI)

4



Neural Signal Acquisition Methods

5



Clinical BCI Research in Pittsburgh

Magnetoencephalography
(MEG)



Electrocorticography
(ECoG)



Intracortical microelectrodes



Motor command

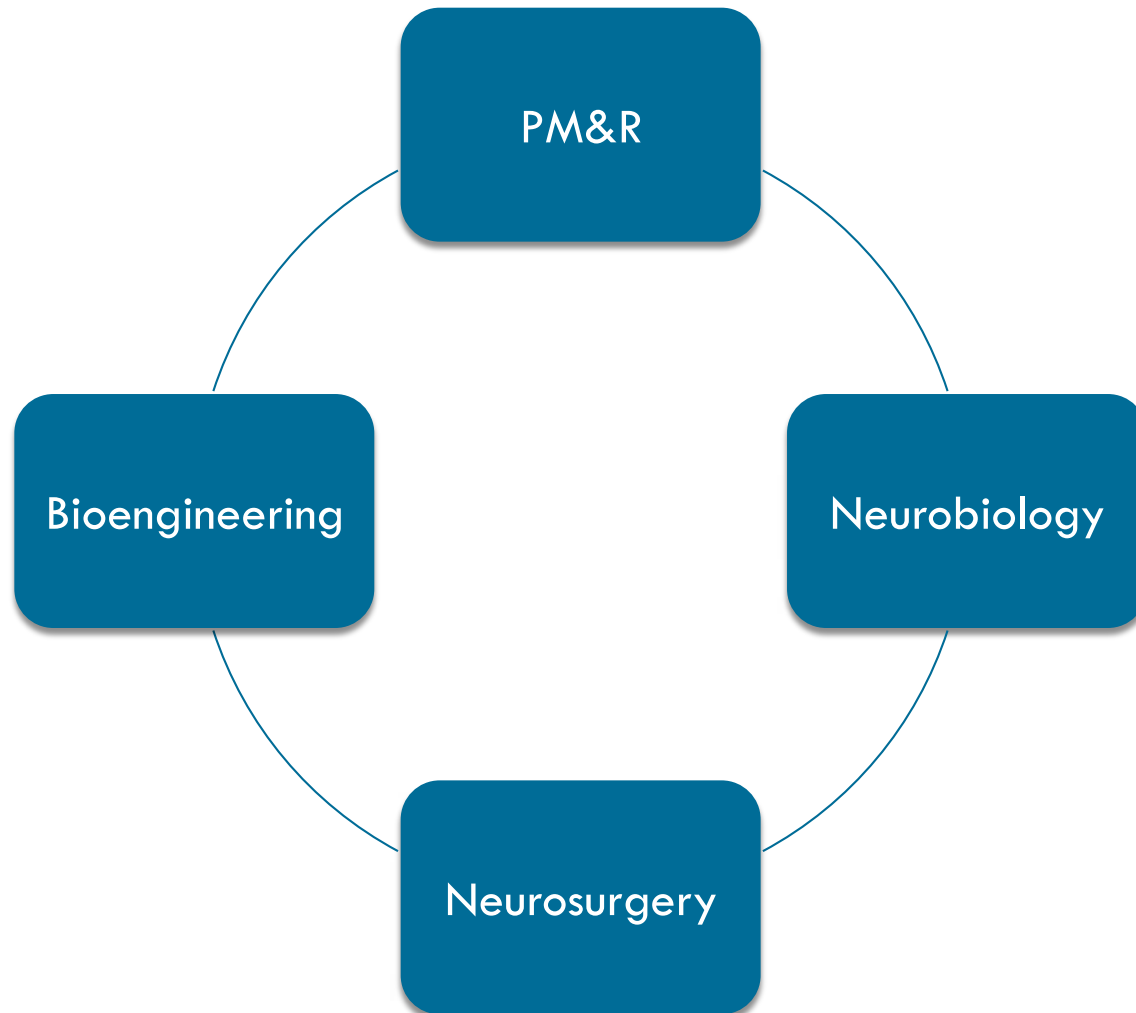


Sensory feedback



Multidisciplinary team

7



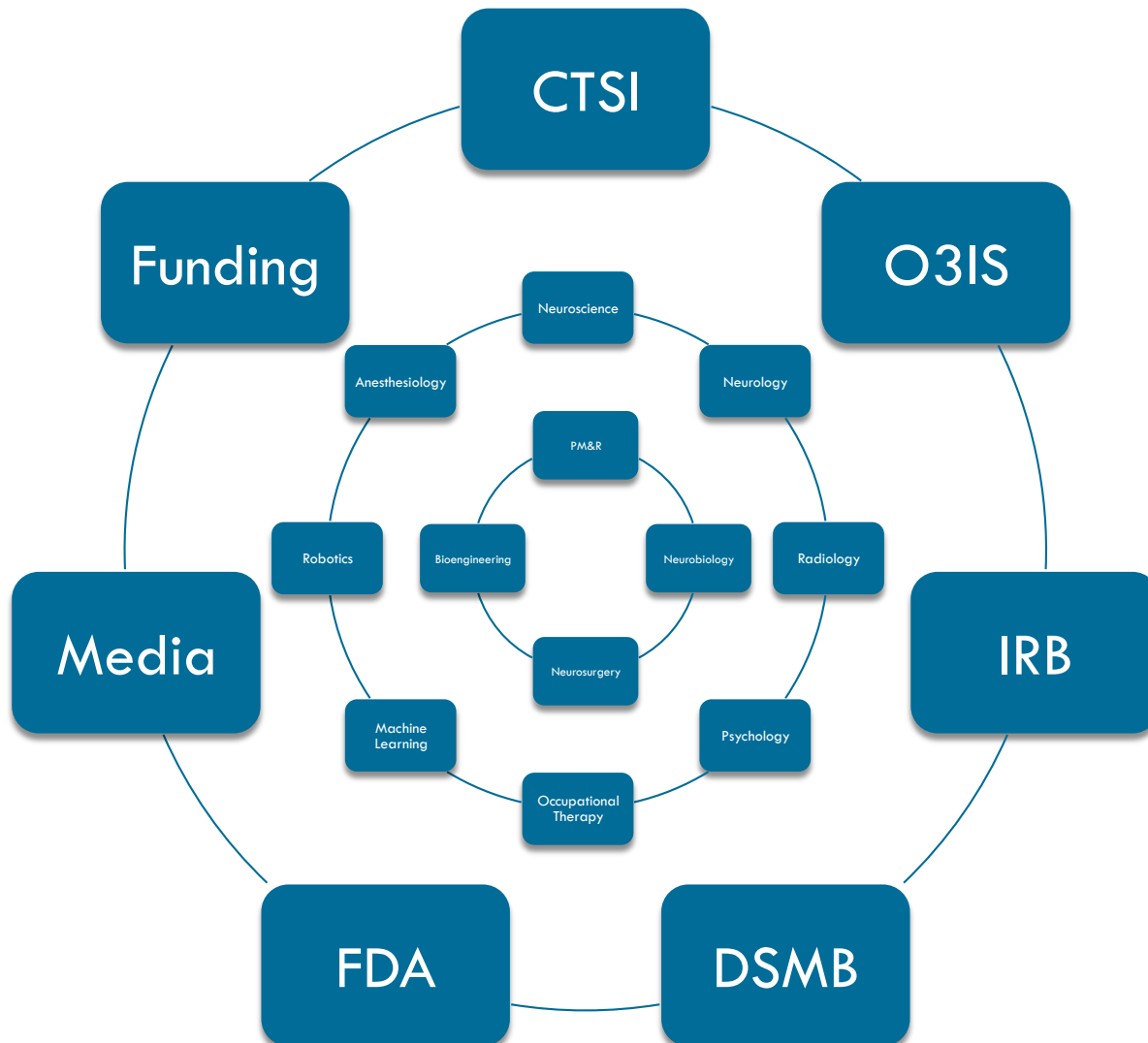
Multidisciplinary team

8



Multidisciplinary team

9



Collaborative Approach in the Development of High-Performance Brain–Computer Interfaces for a Neuroprosthetic Arm: Translation from Animal Models to Human Control

Jennifer L. Collinger, Ph.D.^{1–3}, Michael A. Kryger, M.D., M.S.², Richard Barbara, Ph.D.^{2,*}, Timothy Betler, M.A.^{4,*}, Kristen Bowsher, Ph.D.^{5,*}, Elke H. P. Brown, M.D.^{2,*}, Samuel T. Clanton, Ph.D.^{2,*}, Alan D. Degenhart, B.S.^{3,6,*}, Stephen T. Foldes, Ph.D.^{1,2,6,*}, Robert A. Gaunt, Ph.D.^{2,3,*}, Ferenc E. Gyulai, M.D.^{7,*}, Elizabeth A. Harchick, B.S.^{2,*}, Deborah Harrington, B.S.^{2,*}, John B. Helder, M.S.^{8,*}, Timothy Hemmes*, Matthew S. Johannes, Ph.D.^{8,*}, Kapil D. Katyal, M.S.^{8,*}, Geoffrey S. F. Ling, M.D., Ph.D., F.A.A.N.^{9,*}, Angus J. C. McMorland, Ph.D.^{10,11,*}, Karina Palko, B.S.^{*}, Matthew P. Para, M.E.^{8,*}, Janet Scheuermann, B.A.^{*}, Andrew B. Schwartz, Ph.D.^{2,3,6,10–12,*}, Elizabeth R. Skidmore, Ph.D., O.T.R./L.^{2,13,*}, Florian Solzbacher, Ph.D.^{14–16,*}, Anita V. Srikameswaran, M.D.^{4,*}, Dennis P. Swanson, R.Ph., M.S.^{17,*}, Scott Swetz, M.S.^{8,*}, Elizabeth C. Tyler-Kabara, M.D., Ph.D.^{2,3,12,18,*}, Meel Velliste, Ph.D.^{10,11,*}, Wei Wang, M.D., Ph.D.^{2,3,6,19,*}, Douglas J. Weber, Ph.D.^{1–3,6,*}, Brian Wodlinger, Ph.D.^{2,6,*}, and Michael L. Boninger, M.D.^{1–3,12}

Abstract

Our research group recently demonstrated that a person with tetraplegia could use a brain–computer interface (BCI) to control a sophisticated anthropomorphic robotic arm with skill and speed approaching that of an able-bodied person. This multiyear study exemplifies important principles in translating research from foundational theory and animal experiments into a clinical study. We present a roadmap that may serve as an example for other areas of clinical device research as well as an update on study results. Prior to conducting a multiyear clinical trial, years of animal research preceded BCI testing in an epilepsy monitoring unit, and then in a short-term (28 days) clinical investigation. Scientists and engineers developed the necessary robotic and surgical hardware, software environment, data analysis techniques, and training paradigms. Coordination among researchers, funding institutes, and regulatory bodies ensured that the study would provide valuable scientific information in a safe environment for the study participant. Finally, clinicians from neurosurgery, anesthesiology, physiatry, psychology, and occupational therapy all worked in a multidisciplinary team along with the other researchers to conduct a multiyear BCI clinical study. This teamwork and coordination can be used as a model for others attempting to translate basic science into real-world clinical situations. Clin Trans Sci 2013; Volume #: 1–8

Keywords: brain, clinical trials, methodology, translational research

MEG for Neurofeedback

Motor Rehabilitation: SCI

12

- 225,000-296,000 people in the US with SCI
- Cervical level SCI impairs the ability to grasp and manipulate objects
 - ▣ Impacts independence and social participation
 - ▣ Improvement of hand function is a top priority for functional recovery
- Traditional rehab involves repetition of movements
 - ▣ What if patient cannot voluntarily activate muscles?
 - ▣ Limited improvement ~1 year after injury

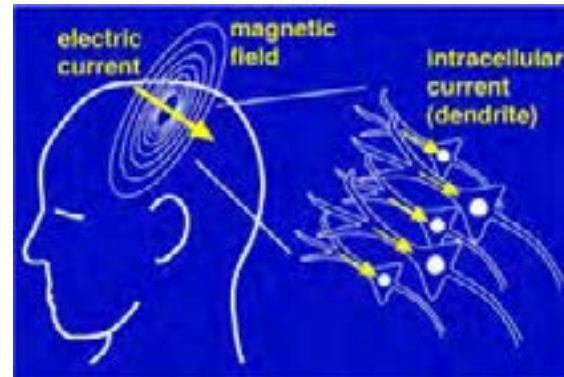
Definitions

13

- **Biofeedback:** The technique of monitoring physiological functions to provide information about these systems, with the goal of being able to manipulate these signals
- **Neurofeedback:** A type of biofeedback that uses real-time displays of brain activity, with the goal of controlling CNS activity. Typically, the goal is to “normalize” brain activity.

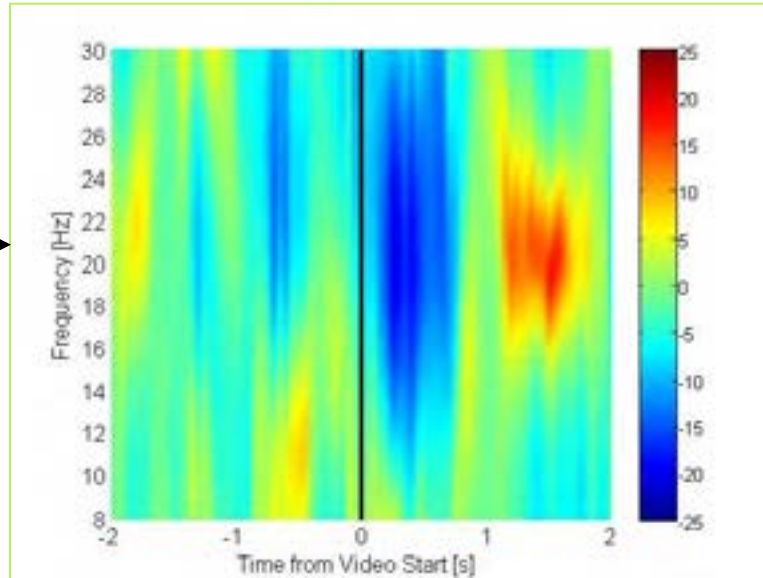
Technology: MEG

14



MEG Neurofeedback

15



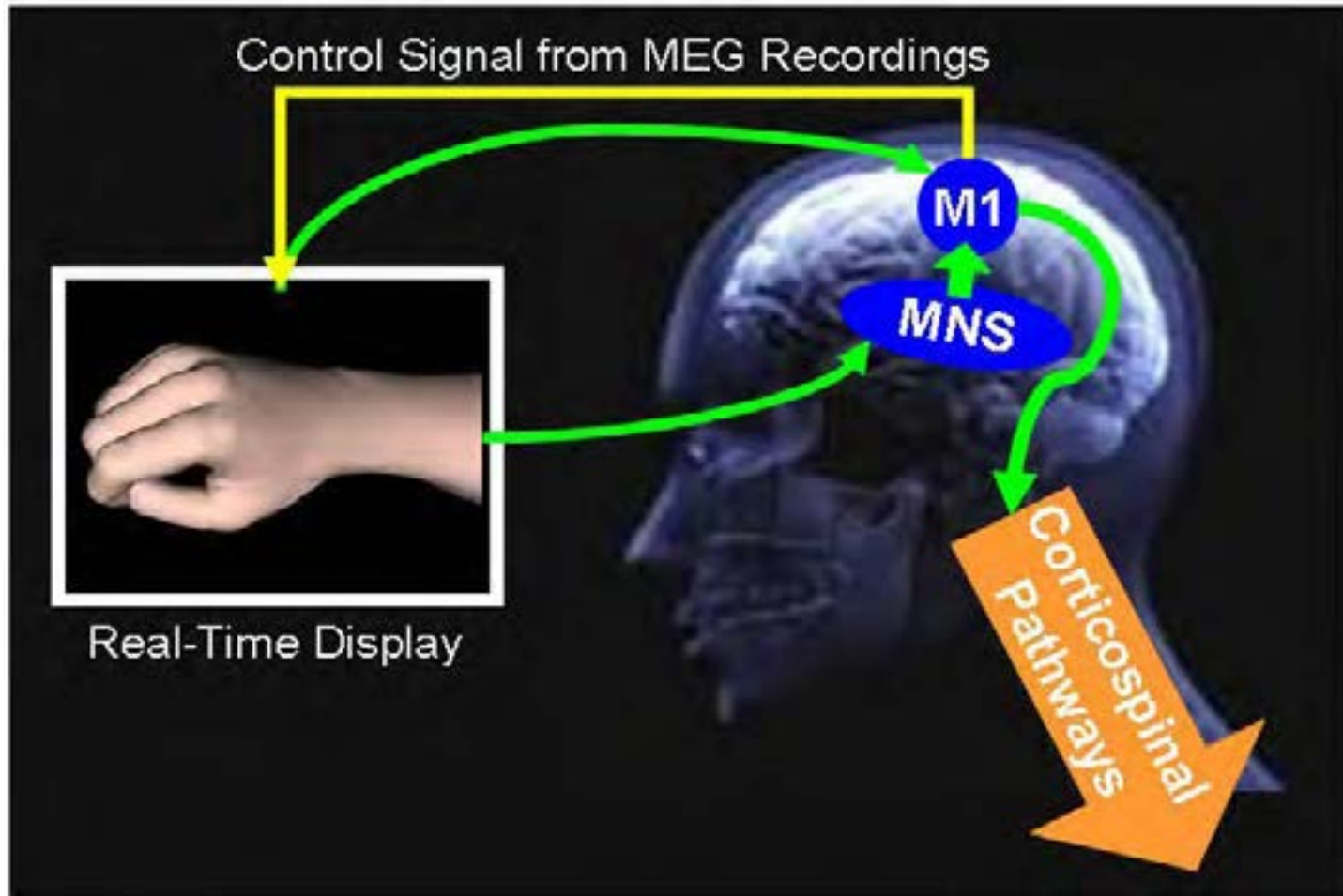
Neural
Decoding



Real-time
Neurofeedback

Facilitation of Motor Cortex Activation

16



BCI as assistive technology

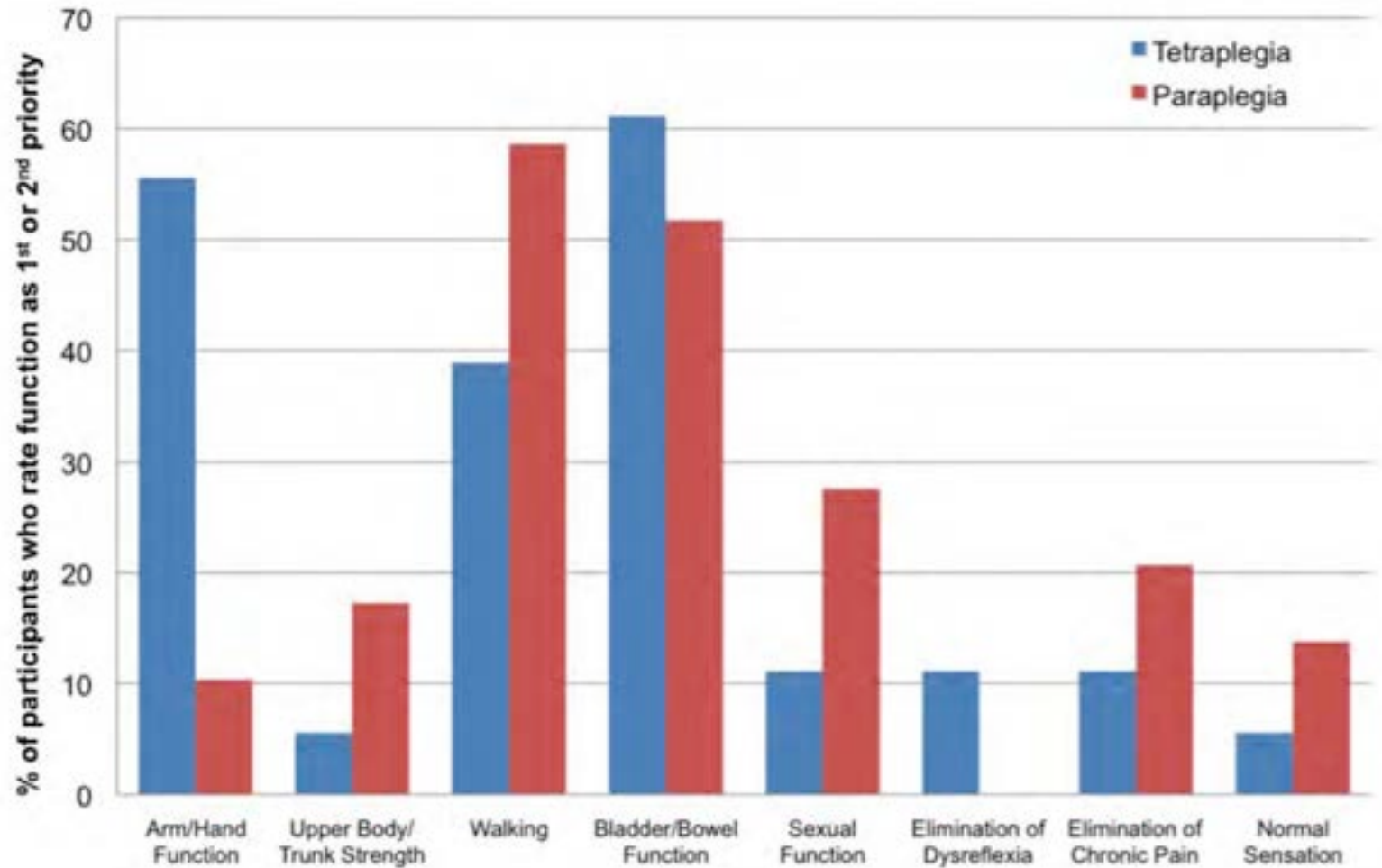
Who are our end users?

18

- People with mobility or communication-related impairments whose needs are not met by traditional assistive technology
- Each diagnosis group or specific impairment may desire different functionality
 - ▣ Recording modality
 - ▣ Risk/benefit tradeoffs
 - ▣ Type of terminal device(s)

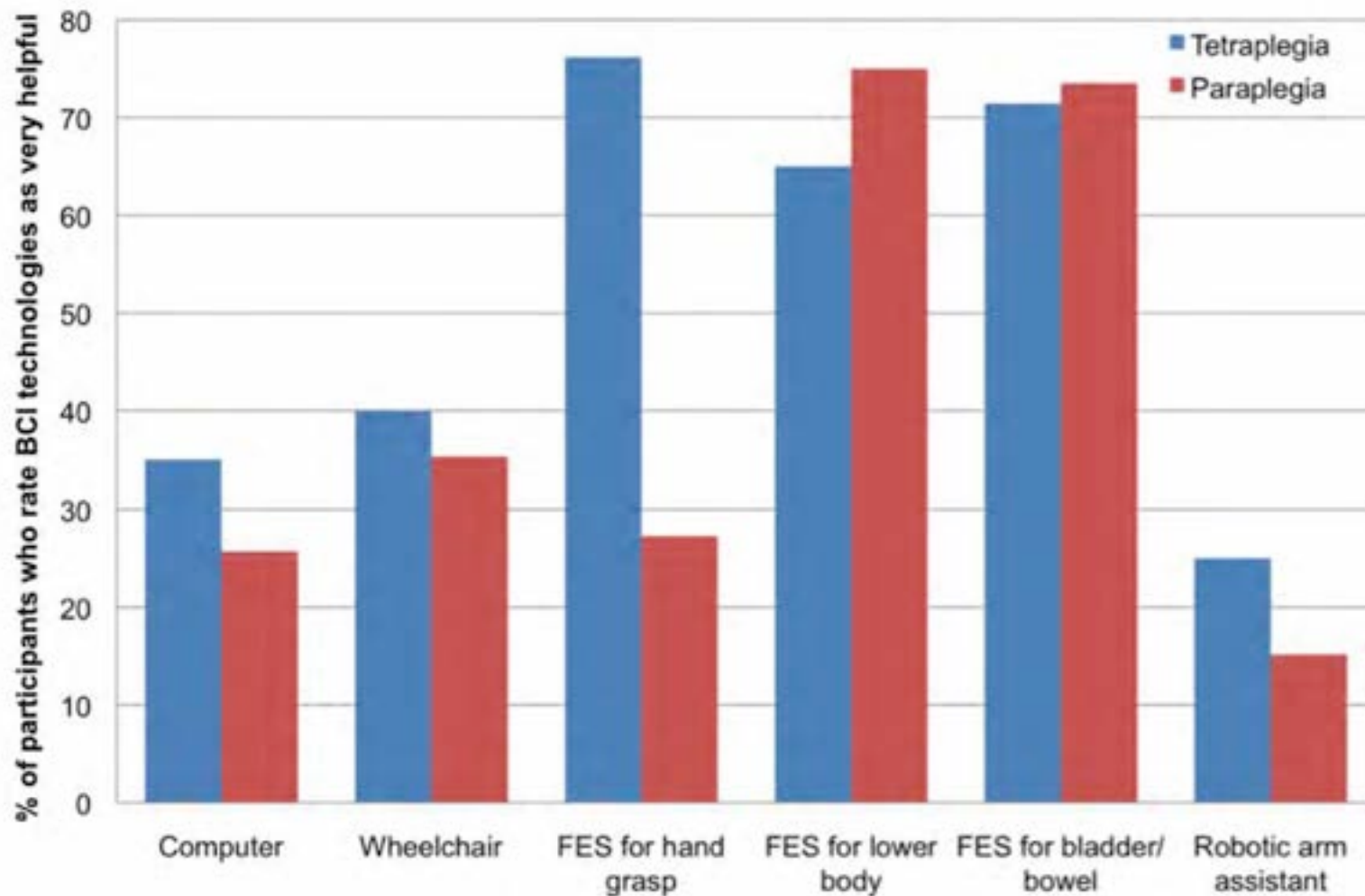
What do they want?

19



BCI-controlled assistive technology

20



BCI design characteristics

21

- Independent operation was most important
- Training time was the least important
- 70% rated non-invasiveness as very important
- More than half would “definitely” or “very likely” consider having surgery to implant BCI electrodes

Priorities for users with ALS

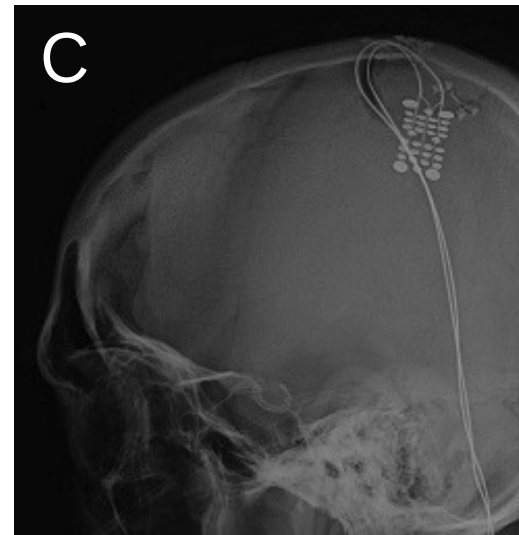
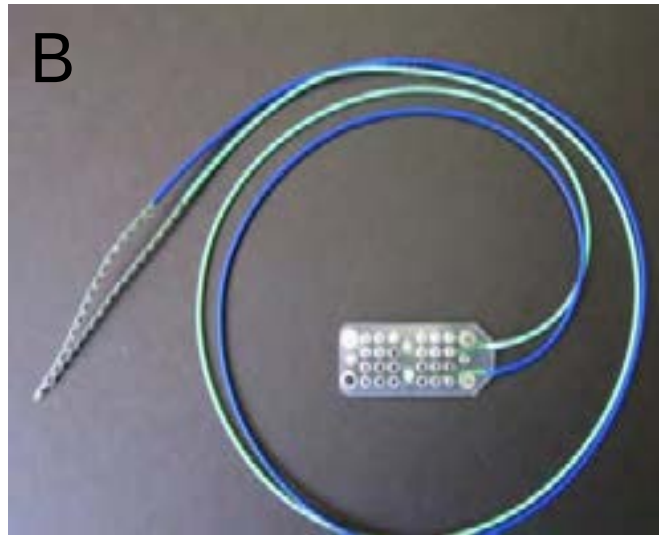
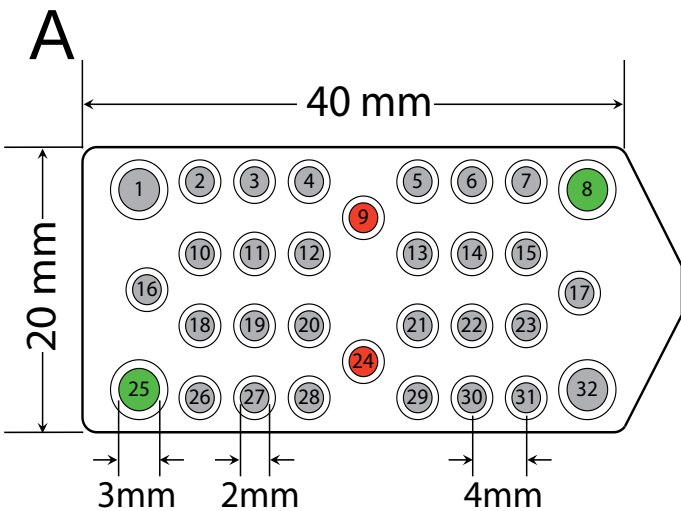
22

- Most important features of a BCI
 - ▣ Accuracy, set-up simplicity, standby mode reliability, available functions
- EEG vs. implanted electrodes
 - ▣ 84% accept electrode cap
 - ▣ 72% accept surgical implant (outpatient)
 - ▣ 41% accept surgical implant (short hospital stay)
- BCI-controlled assistive technologies
 - ▣ Power wheelchair and robot arm control trended towards a more significant interest

EC_oG BCI

ECoG BCI: First Participant

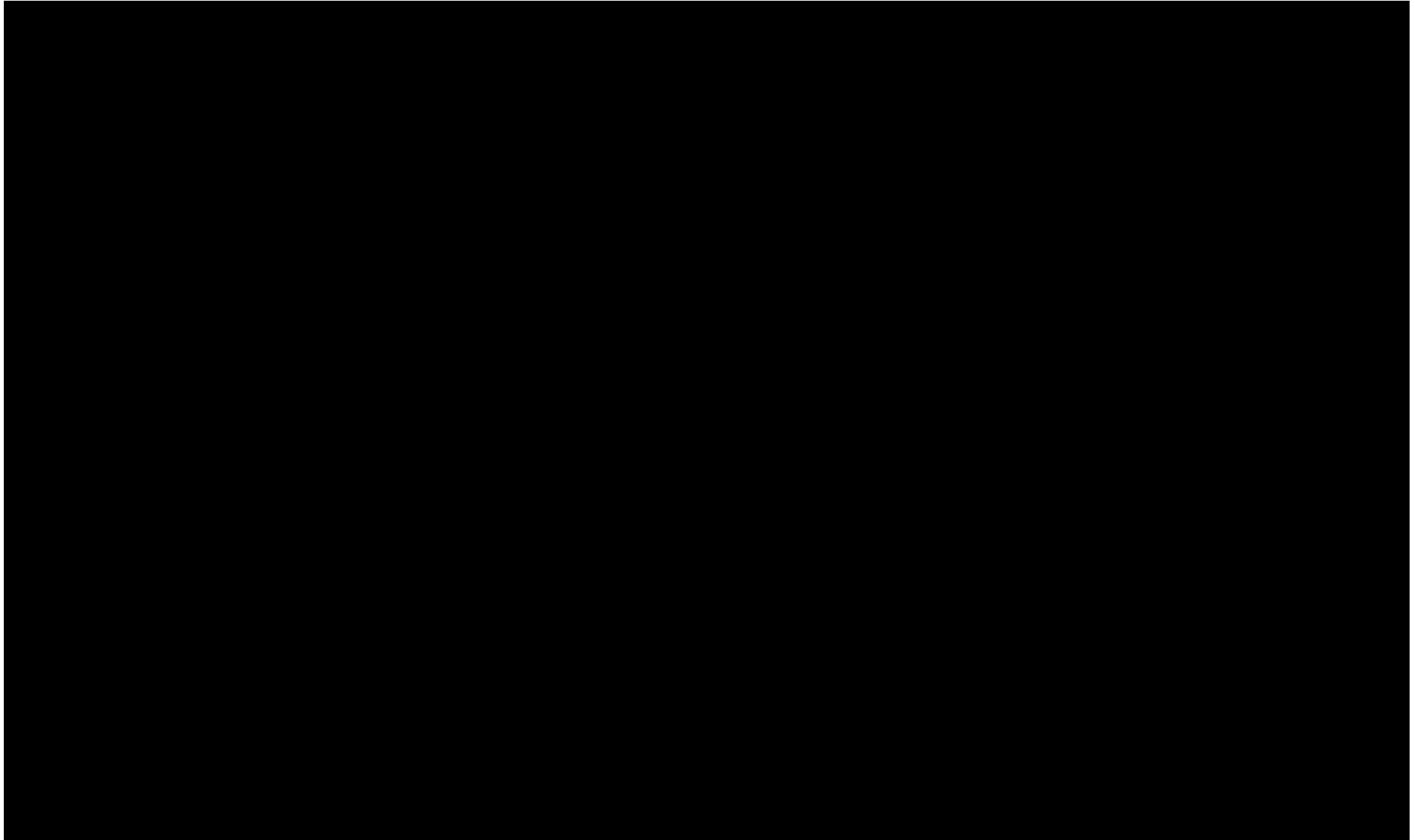
24



- A short-term study over 28 days (21 testing days)
- Subject: 30-year old male, C4-level spinal cord injury

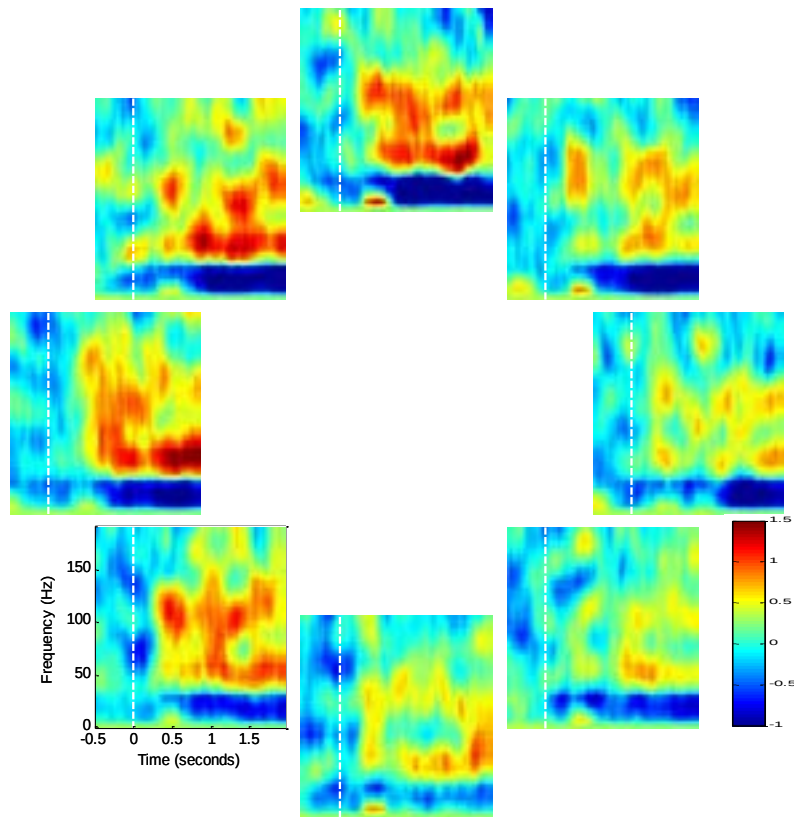
2D Cursor Control

25

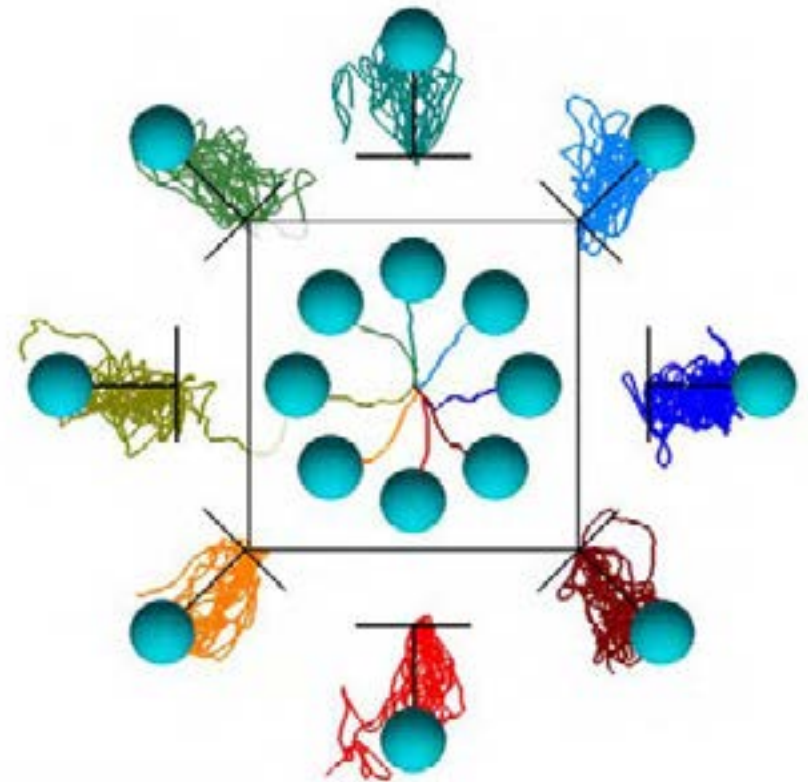


ECoG signal modulation and 2D cursor trajectories

26



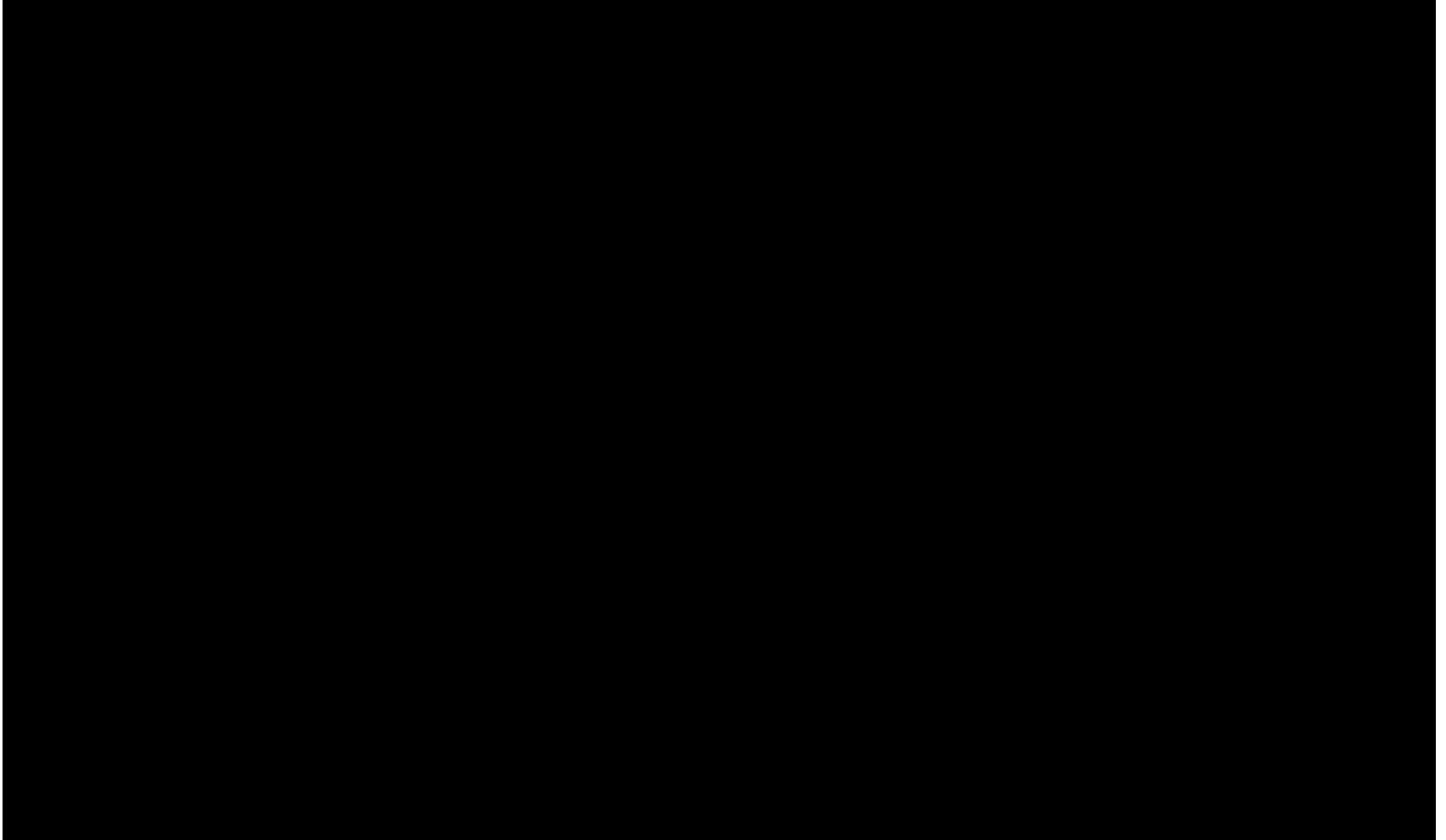
Channel 4



Average success rate: 87% over 176 trials

3D Cursor Control

27



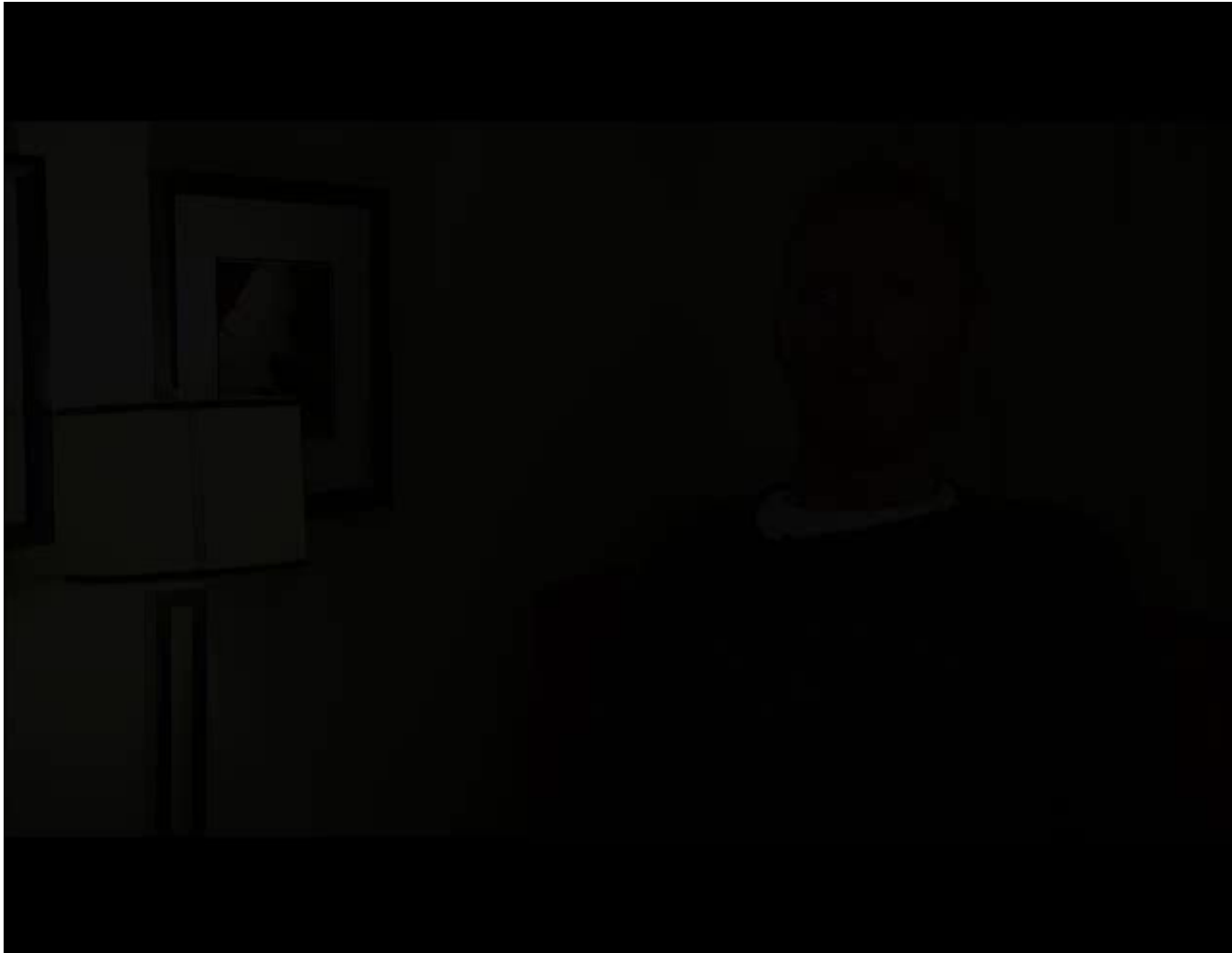
3D Control of the MPL

28



Meet our participant

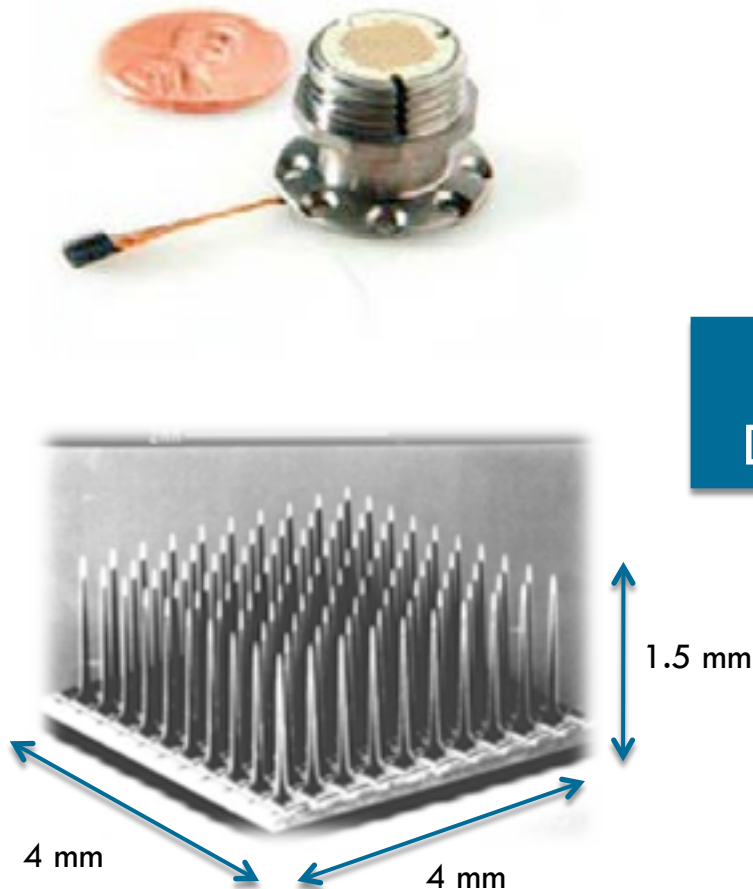
29



Intracortical BCI

Intracortical BCI for robotic arm control

31



Neural
Decoder



Conducted under an FDA Investigational Device Exemption

Collaborators: Device Regulation

32

- Blackrock Microsystems



- Johns Hopkins University
Applied Physics Laboratory

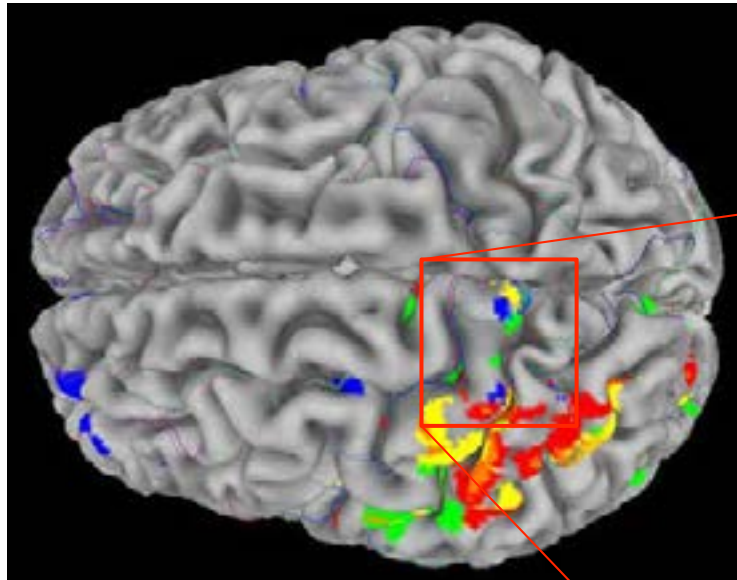


- FDA: Investigational Device Exemption
 - ▣ Basic science research
 - ▣ Clinical protocol development

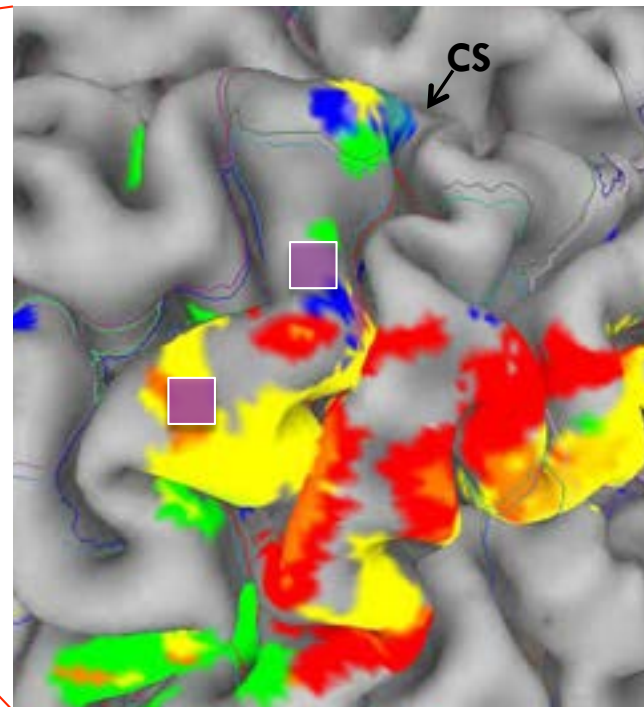


Presurgical planning

33

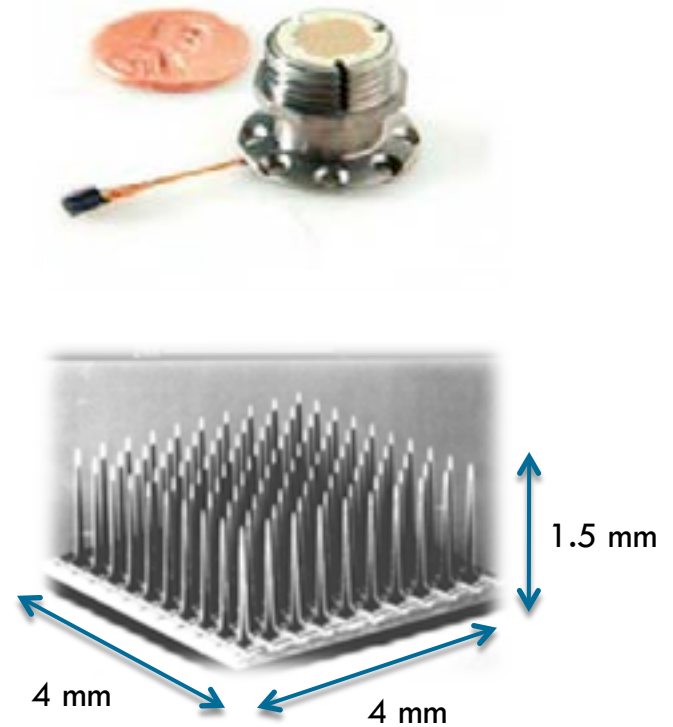
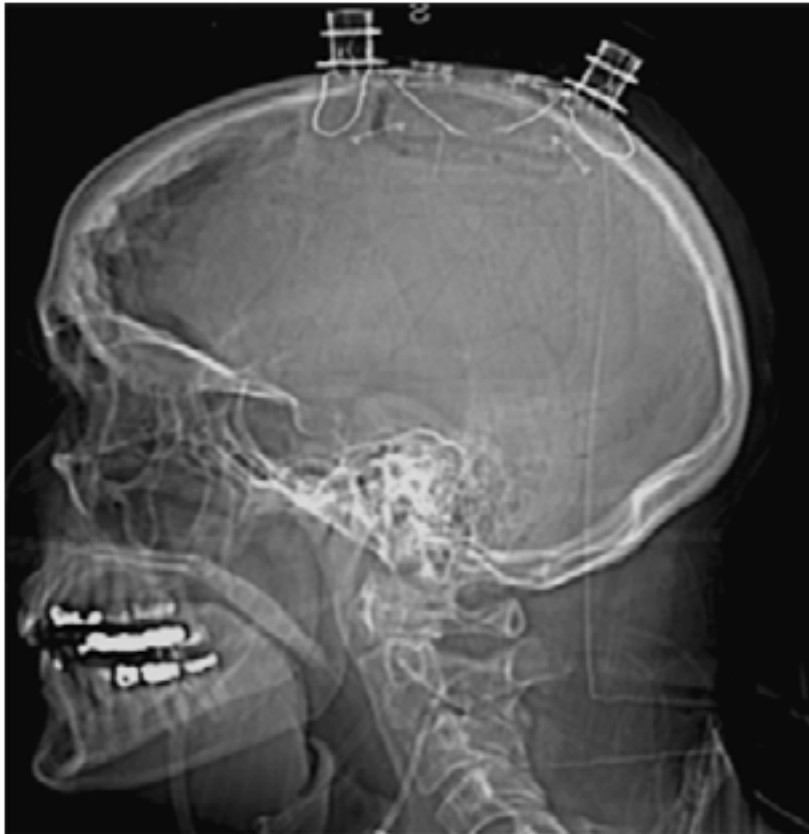


Hand grasp **RED**
Shoulder shrug **BLUE**
Lip pursing **GREEN**
Complex finger **YELLOW**



Implantation surgery: 2/10/12

34



Collaborators: Surgical

- Neurosurgery
 - ▣ Minimize risk, ensure device function
- Neurophysiology
 - ▣ Array placement
- Anesthesiology
 - ▣ Screening for co-morbidities
 - ▣ Special considerations
 - tetraplegia, spastic, or flaccid paralysis
 - autonomic hyperreflexia
 - receptor up-or-down regulation at the neuromuscular junction
 - cervical fusions
 - tracheostomy
- Psychology



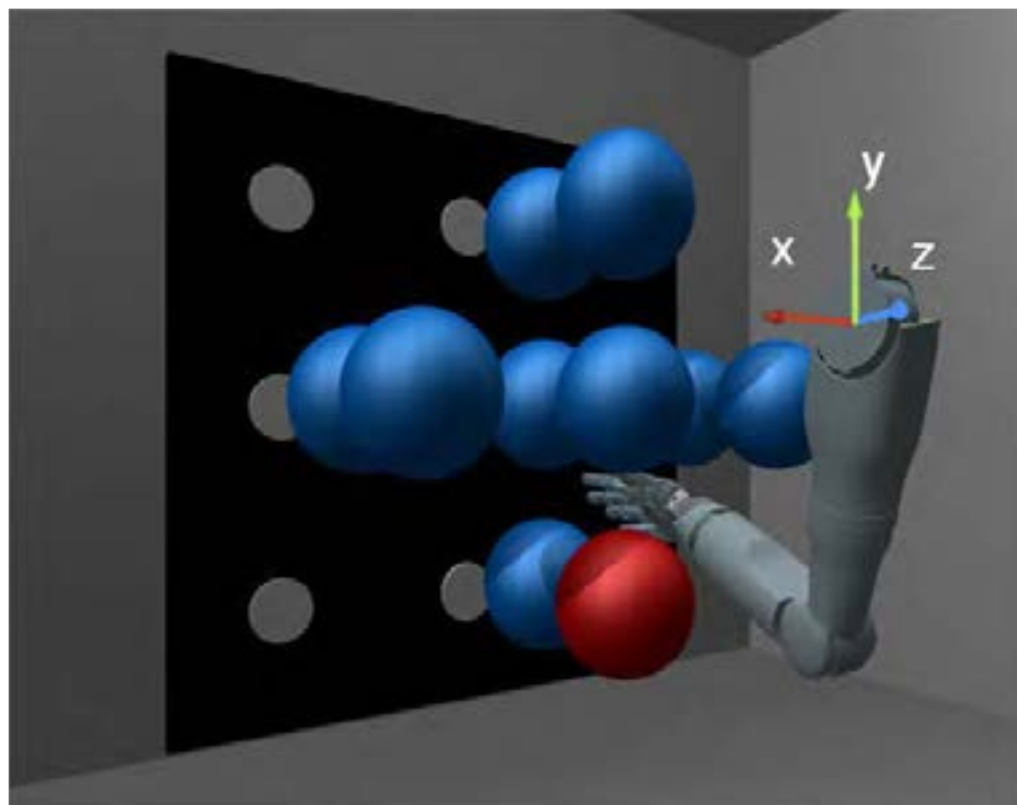
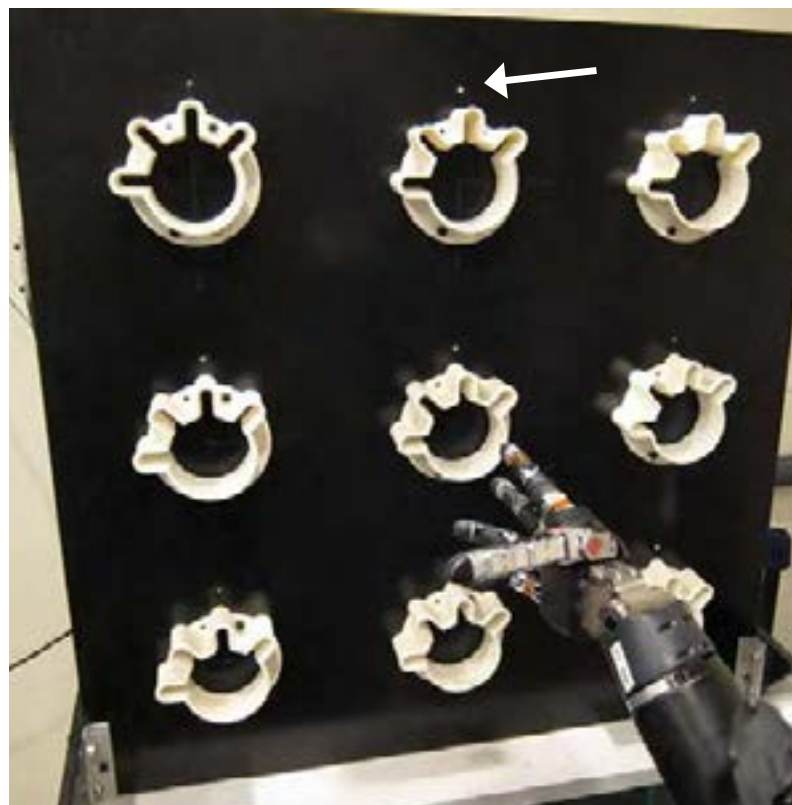
3D control: 2/21/12

36



7D sequence task

37



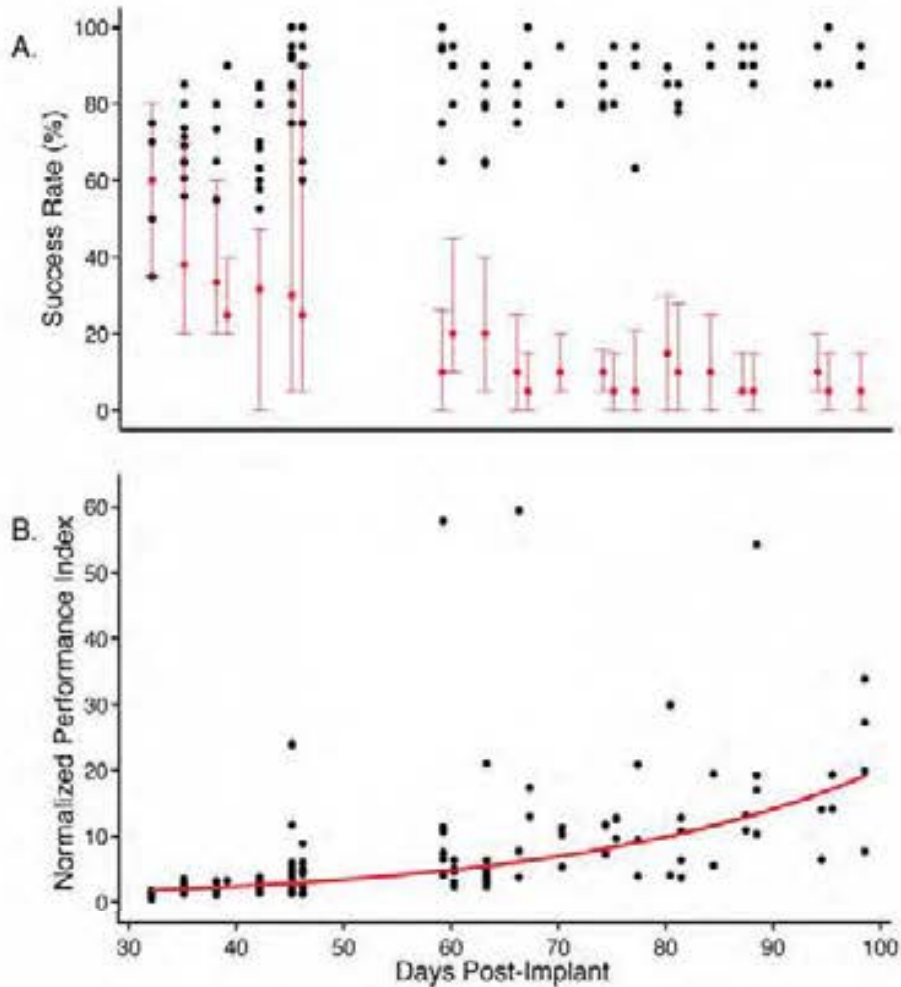
7D sequence task: 5/14/12

38



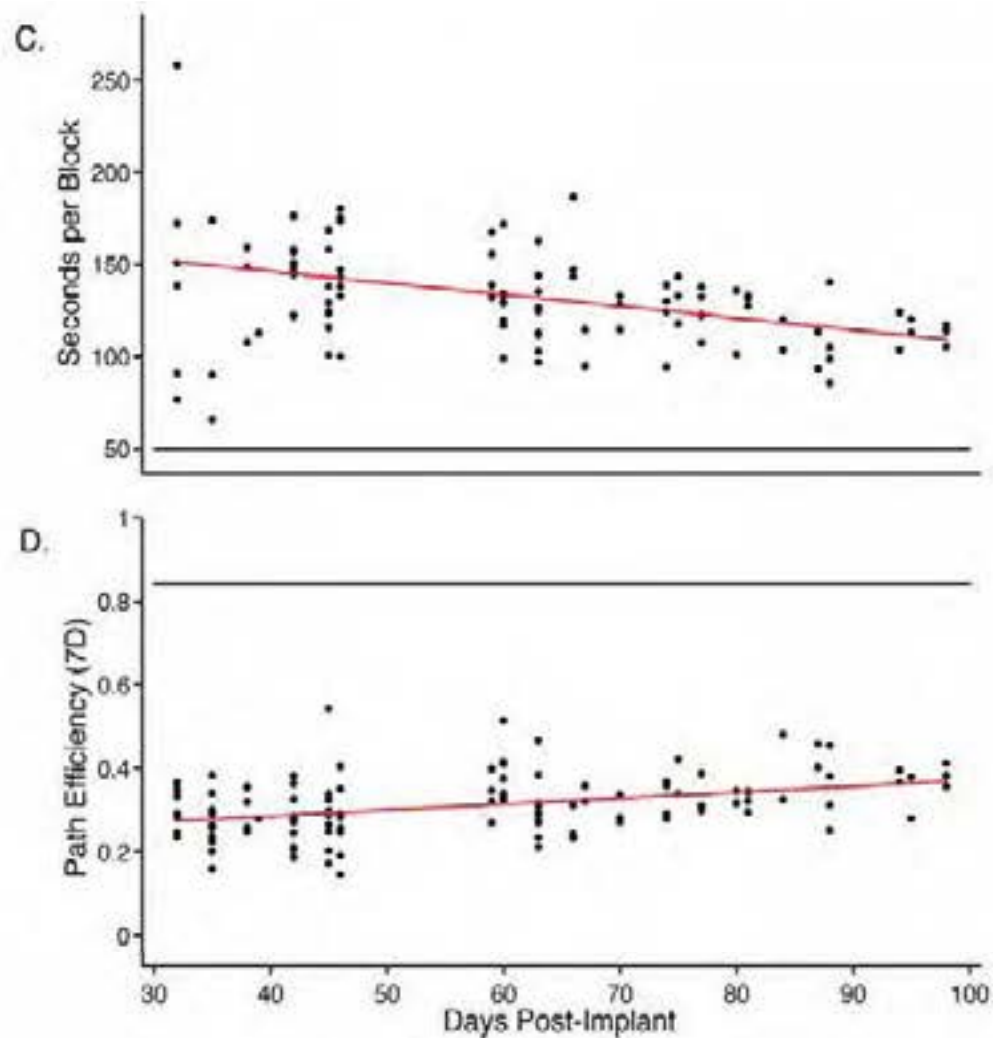
Results: 7D performance

39



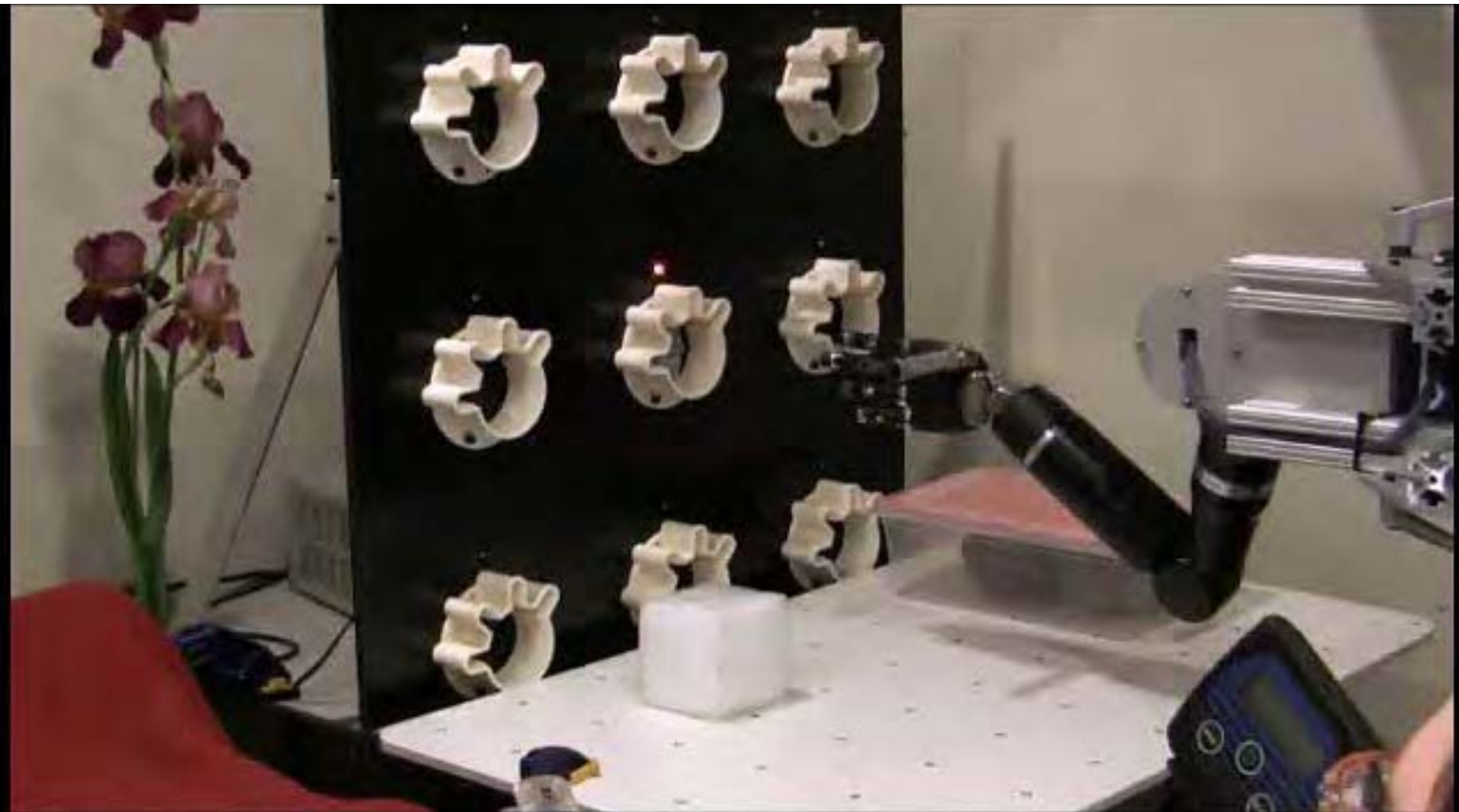
Results: 7D performance

40



Action Research Arm Test (ARAT)

41



ARAT Performance

42

- 9 of 19 possible tasks were evaluated



- Each scored from 0-3
- Score ranged from 15-17 (out of 27) with BCI
- Δ 5.7 points is clinically significant
- Mean completion time ranged from 9.5-21.3 s

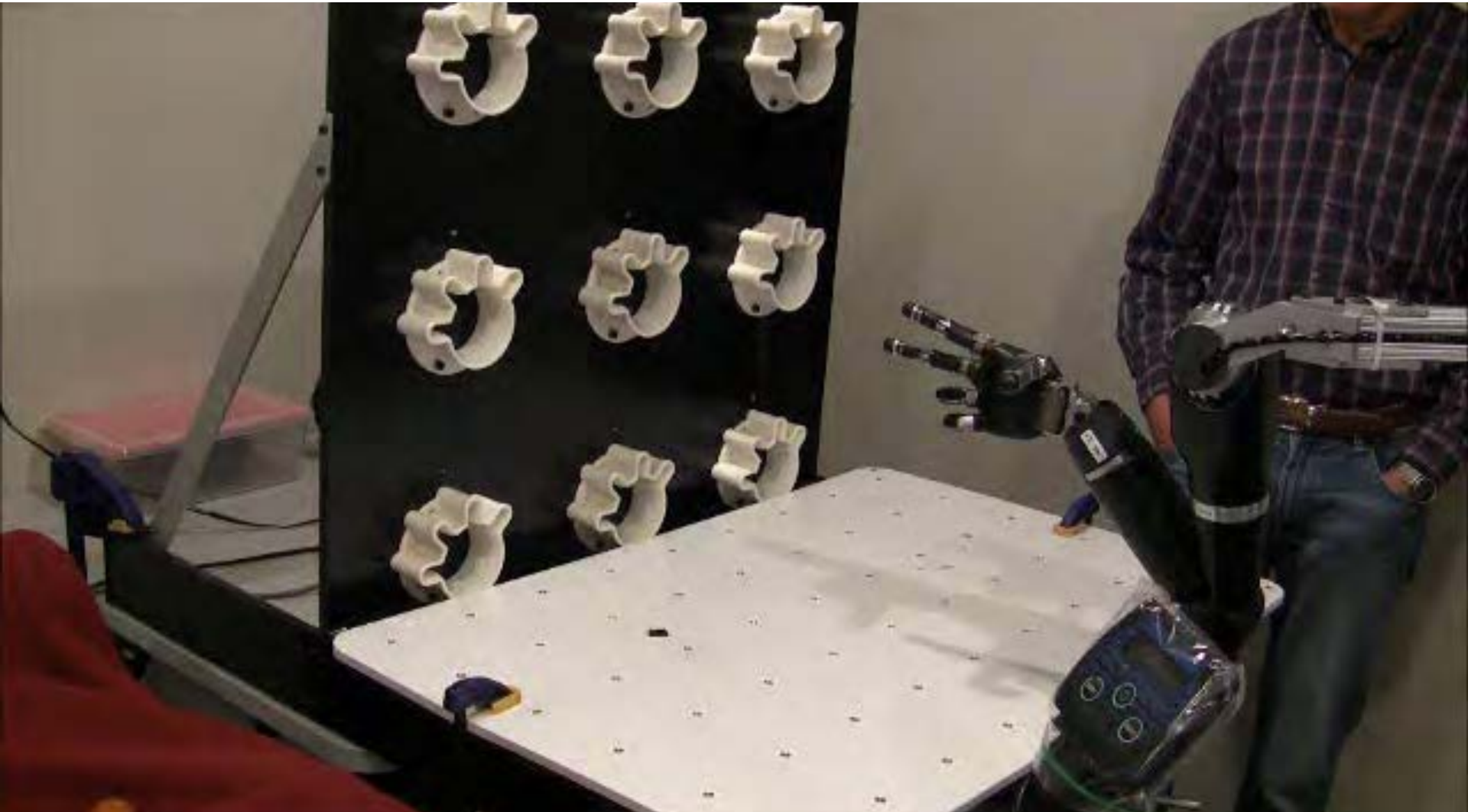
Different grasp strategies

43



Hand shaping (8D control)

44



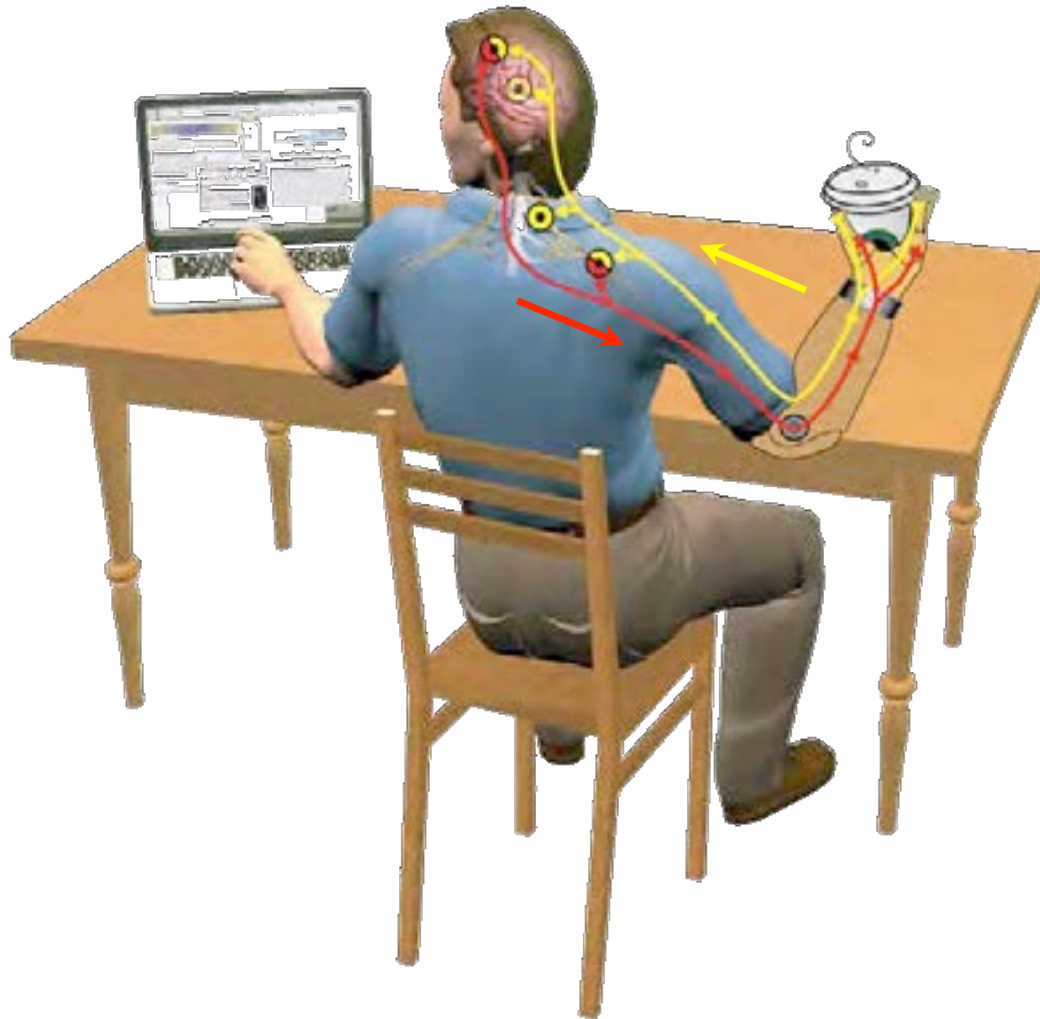
Chocolate

45

Chocolate

Sensory feedback is crucial for normal motor control

46

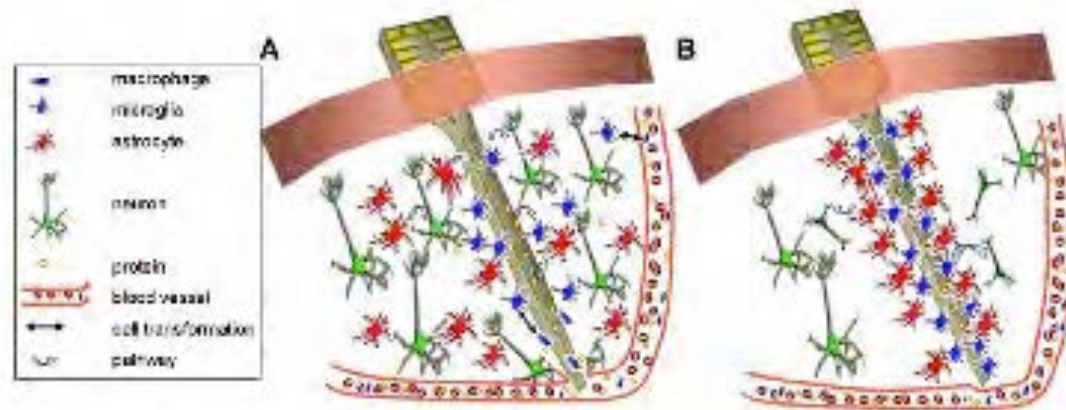


Barriers to Clinical Translation

Recording quality/stability

48

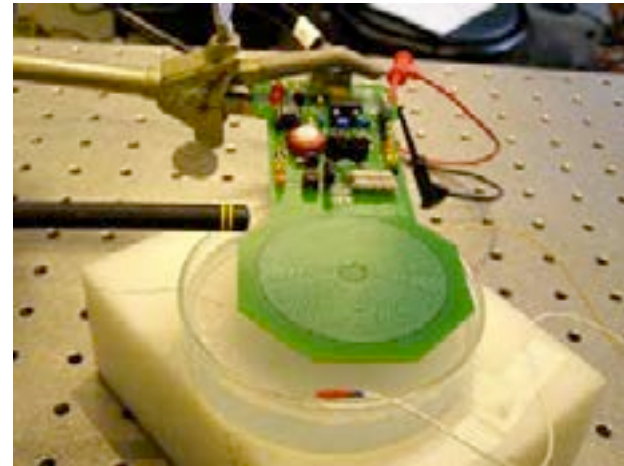
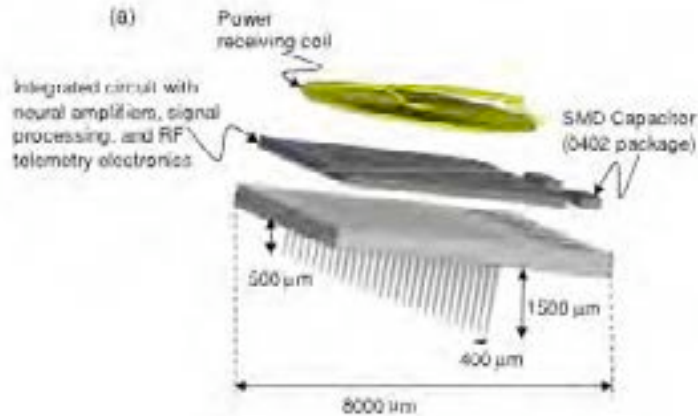
□ Host/tissue interface



- Possible solutions: Electrode geometry, materials, coatings
- Resolution vs. invasiveness tradeoff
- Effects of distractions/noise
- Recalibration

Telemetry

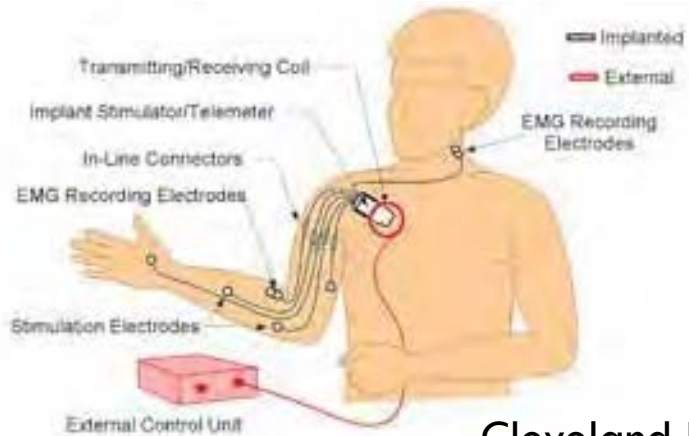
49



- Reduce infection risk
- Independent operation
- How much information is needed?
- Data acquisition system portability?
- System complexity

Integration with other technology

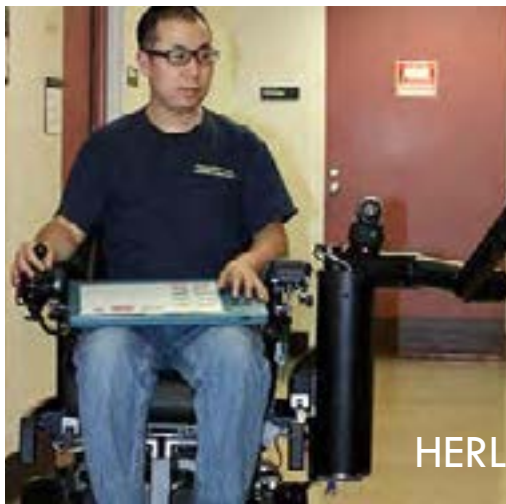
50



Cleveland FES



JHU



HERL



UC Santa Cruz



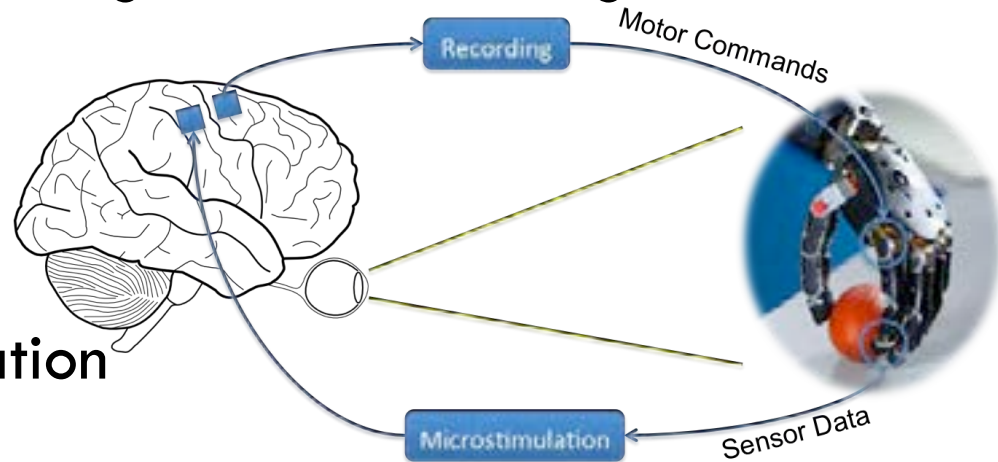
DEKA

Sensory feedback

51

□ Each modality has advantages and challenges

- ▣ Visual
- ▣ Non-invasive
- ▣ Cortical surface
- ▣ Intracortical microstimulation
- ▣ Optical stimulation
- ▣ Peripheral nervous system



Other challenges?

52

- Meeting performance expectations
- Independent operation or remote monitoring
- Cost
- Clinician and patient education

Summary

53

- BCIs have applications for rehabilitation and assistive technology
- An intracortical BCI enabled a participant to perform natural reaching and grasp movements with skill approaching that of an able-bodied individual
- Additional work is needed to overcome barriers to clinical translation → multidisciplinary team

Acknowledgments

54

- Funding
 - ▣ DARPA
 - ▣ NIH
 - ▣ VA
- Faculty collaborators
 - ▣ Michael Boninger
 - ▣ Andrew Schwartz
 - ▣ Rob Gaunt
 - ▣ Wei Wang
 - ▣ Doug Weber
 - ▣ Elizabeth Tyler-Kabara
 - ▣ Elizabeth Skidmore
- External collaborators
 - ▣ JHU APL
 - ▣ Blackrock Microsystems
- Post-docs/students/staff
 - ▣ Brian Wodlinger
 - ▣ Stephen Foldes
 - ▣ Michael Kryger
 - ▣ Meel Velliste
 - ▣ Angus McMorland
 - ▣ Elke Brown
 - ▣ John Downey
 - ▣ Sharlene Flesher
 - ▣ Danielle Rager
 - ▣ Alan Degenhart
 - ▣ Debbie Harrington
 - ▣ Jeff Weiss
 - ▣ Max Maguire
- **Study participants**

Thank you

55

